Chapter 1
Introduction to Biomass Combustion

Abstract The role of biomass in the world energy scene is first considered and compared with other energy sources. Estimates of the resources available are provided and discussed. The IEA world estimates of the growth in the use of biomass are also presented. Issues resulting to Greenhouse Gas emissions and sustainability are considered.

Keywords Biomass availability · Resources · Greenhouse gases

1.1 The Role of Biomass Combustion in World Energy

Solid biomass consists of material of recent organic origin which has not yet undergone the process of metamorphosis that leads to peat and coal. It consists of three major components, cellulose, hemicellulose and lignin together with small amounts of solvent extractable organic materials as well as traces of inorganic compounds. These inorganic materials end up as ash and this term is commonly applied to this material before it is burned. Peat is not defined as a biomass. Charcoal is a very important derived biofuel (Antal and Gronli 2003). The boundary between biomass and waste is not well defined since the definition varies from country to country and can depend on local legislation. Here we include forestry and agricultural waste but not domestic, sewage or food industry waste although there may be many similarities in their properties.

Biomass was the major fuel in the world until the late 1,800 hundreds when coal then became dominant. The combustion of solid biofuels as a primary energy source has again grown significantly in the last decade principally because it can be used to replace the fossil fuels, coal, oil and natural gas. This is because it is a renewable energy resource and it offers neutrality or near-neutrality with respect to carbon dioxide emissions. It is derived from plant matter which is produced by photosynthesis from carbon dioxide in the atmosphere.

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However, similar to fossil fuels there are some adverse consequences in its use as a fuel such as the formation of smoke, oxides of nitrogen and other environmental pollutants. Biofuels may arise from energy crops grown specifically for this purpose or are by-products from industrial process such as paper-making, or as agricultural wastes such as straw. This use as a fuel is in competition with biomass other uses such as the production of commodities such as food—the food versus fuel issue, or paper, fibreboard, furniture or bio-motor and aviation fuels, and as a feedstock for the chemical industry. A number of major reviews that have considered their utilisation and the environmental aspects of different processing technologies for example, Stevens and Brown (2011), Bridgwater et al. (2009), Spliethoff (2010).

The combustion of solid biomass thus covers a wide range of materials, woods, straw, agricultural residues processing wastes from paper manufacturing, and also algae and seaweeds. The broad use of the term biomass also includes related materials such as, manures, meat by-products and black liquor from paper making industries. Peat is not included but is similar from a combustion point of view and widely used as a fuel. Historically the major fuel has been wood; two centuries ago biomass provided almost 100 % of the energy used in the world and about 60 % a century ago. It is a major source of energy now in Africa, Asia and China. For example, biomass currently provides 78 % of the total energy in Nigeria.

At the present time biomass provides about 10 % of the world energy. Table 1.1 shows the current profile of energy use on a global basis in 2012. There are reasonably accurate statistics of the quantities of fossil produced and used (BP 2014) and also of renewable energy usage where the amounts used are reported. The main difficulty arises with the quantification of the large quantities of biomass used in the developing countries where records are not kept.

Of this the main application is in heating. Roughly two thirds is used in developing countries and the rest is in industrialised countries. The usage for steam raising and large electrical generation units is relatively small at about 15 %. The amount of liquid biofuels for transport is included for comparison and is small compared to the others (4 %). The approximate amounts used are shown in Table 1.2.

A number of analyses have been made of the future development of biomass but these predictions are complicated by political incentives such as carbon taxes and subsidies. The IEA have made the prediction of energy usage in the next 25 years using a scenario approach in their World Energy Outlook (2013) publication. The

Table 1.1 Global energy consumption in 2013

Fossil fuels oil, coal, natural gas	10.98 Gtoe
Nuclear	0.58 Gtoe
Hydro-electricity	0.86 Gtoe
Wind, solar, biomass	0.28 Gtoe
Biomass-not recorded, mainly in developing countries	1–1.5 Gtoe
Total-commercial Total-all uses	12.73 Gtoe 14 Gtoe approximately

Source For commercial recorded data: BP (2014)

Table 1.2 Main applications of biomass

Domestic cooking and heating. Heating of commercial premises-schools, large buildings	1 Gtoe
Industrial steam raising-waste biomass, medium size power generation/CHP/district heating units	0.19 Gtoe
Large electrical power plants	0.17 Gtoe
Transport	0.08 Gtoe

Source IEA Bioenergy (2013)

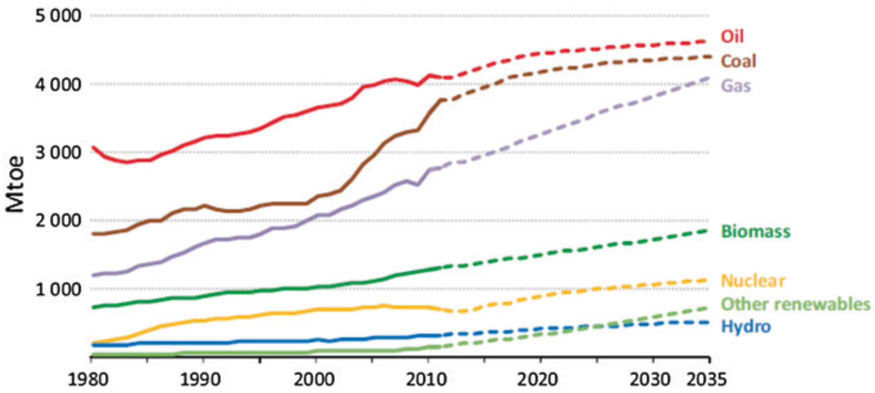

Fig. 1.1 IEA estimates of the world energy use until 2035 (World Energy Outlook 2013, with permission)

'New Policies Scenario' which is the middle of three options is shown in Fig. 1.1. The increase in future energy demand shows some levelling off in fossil fuel usage and an increase in the use of renewable energies especially biomass.

Predictions on the future usage of biomass have been made as far as to 2,100. It has been estimated that the contribution from bioenergy (liquid and solid fuels) could be raised to 200 EJ/year (4.8 Gtoe) by 2050 and possibly five times greater (IEA Bioenergy 2008).

Early biomass usage was based on open fires which had low efficiencies, typically 5–10 %, but this has significantly improved over the last hundred years. Local supplies were used which needed little in the way of processing, other than seasoning. This use developed widely especially in countries with considerable reserves of biomass, forested areas or bio-waste from sugar or paper industries, as shown in Table 1.3. This technology is still widely used in Developing Countries today despite major efforts to make other technologies available for cooking such as solar cookers. More recently an international trade has developed which is changing the world picture because of the need of fuels that are readily transported and stored without degradation or significant fire risk. A further factor in the present day application of biomass is that combustion requires much more consistent fuel quality and lower emission levels and so fuel pre-treatment may be necessary. This may involve pelleting or torrefaction which are described in Chap. 2.

Table 1.3 Use of solid biomass in the industrial sector in 2009 (IEA Bioenergy 2013)

Country	Primary solid biomass (Mtoe)	% Share of global use
Brazil	31	18
India	29	16
United States	25	16
Nigeria	9	5
Canada	7	4
Thailand	7	4
Indonesia	7	4

Today there is increased emphasis on the use of renewable energy sources in many industrialised countries and one of the options is biomass combustion for heat and electricity production. Bioheat, the oldest technology (Webster 1919; Tilman et al. 1981), is now moving to a more technically advanced stage in many industrialised countries (Bridgwater et al. 2009; Spliethoff 2010). This is a result of the environmental pressures resulting from climate change concerns arising from the release of GHG, and secondly because of security of energy supplies. Of the alternative renewable supplies biomass has fewer negatives since it is geographically widely available and it is storable. The major issue is the balance between the advantages presented in the fact that it is CO_2 neutral compared with the associated pollution, and the impact that it may have on food production and price. Some of the combustion applications result in a significant atmospheric pollution -indeed it is estimated that 1.5 million people die per annum as a result of this type of pollution (WHO 2014). Solid biomass fuels are in competition with the use as liquid biofuels or chemical feedstock, but the two could be integrated with the bio-waste from the processing application being used as solid fuel. The first generation of liquid biofuels were produced with minimal processing and low efficiency but the second generation has greater flexibility in the conversion into a variety of products. A number of factors have to be taken into account and the estimated GHG emissions associated with the bioenergy feedstocks or delivered energy can be estimated using life cycle analyses, and these are very important as well as economic factors. Thus in the UK the GHG emissions using various feedstocks and emissions savings compared with coal and gas were calculated for the UK by the UK Environment Agency (2009). The figures are listed in Table 1.4.

This type of information can be obtained for both supply and utilisation using Life Cycle Assessment (LCA) by means of a ‘Biomass Emissions Calculator’. Such a Calculator was developed in the UK by DECC (The Department of Energy & Climate Change). These types of calculations are subject to a considerable amount of debate because of the assumptions made especially when it involves importing large quantities of biomass from North America and elsewhere for electricity generation. A more sophisticated calculator has been developed which looks at the changes in the amount of carbon stored in forests in North America when assessing the benefits and impacts of various bioenergy scenarios (Stephenson and MacKay

Table 1.4 GHG savings from various types of biomass feedstocks

	Feedstock	Emissions ($kgCO_2e/MWh$)
Chips	UK forestry residue	10
	Imported forestry residue	22
	Waste wood	7
	Short rotation coppice (SRC)	17
	Miscanthus	18
Pellets	UK forestry residues	38
	Imported forestry residue	50
	Waste wood	51
	Imported waste wood	66
	SRC	100
	Miscanthus	65
Other	Olive cake	9
	Palm Kernel expeller (PKE)	82
	Straw	73

2014). It gives information about which biomass resources are likely to have higher or lower carbon intensities, and so provides insight into a complex topic. In future this type of calculation will have to be made to make comparison with liquid biofuel production and other competing uses including the wood utilising industries. Like all models they are sensitive to the input data and the model assumptions.

1.2 Resources—Supply of Biomass

The current resource base for biomass fuels is about 1,000 Gtoe and is renewable and effectively infinite but only if the rate of growth is greater than the rate of usage. That is, if it is used in a sustainable way. The total amount of fuel available at some future time t, R_T, is given by:

$$R_T = [\text{The current resource base}] + \left[\text{The rate of growth}\right] - [\text{The rate of utilisation}]$$

But the rate of utilisation is the aggregate of the use of biomass for food, manufacturing industry (paper and furniture) and other process as well as a fuel. This is largely determined by the world population and whether this reaches an equilibrium level which is sustainable.

The usage of biomass is dependent the technology available, the environmental impact, the energy costs which are very dependent on subsidies paid by governments and ultimately the availability of the biomass at what is considered to be an economic price. Current and future estimates of biomass utilisation are subject to uncertainty and global values can vary by a factor of 5 but well-resourced information is available for major countries such as the US, Europe, Russia, China, India and Brazil. The upper estimate of biomass annual availability (Smeets et al. 2007; Faaji and Londo 2010; Slade et al. 2011) is about 2,500 EJ (60 Gtoe) [1 EJ = 24 Mtoe] and is almost six times the world current energy requirement. Resources vary from country to country and are dependent on geographic location, the climate, the population density and the degree of industrialisation of the country.

It is seen from Table 1.1 that the present amount of energy derived from biomass is about 8–15 % of the total annual energy used. Essentially biomass used as a fuel can be divided into the following two major groups:

1. Biomass, grown directly for use as an industrial primary fuel,
2. Traditional bioenergy (e.g. biomass for cookstoves).

The amount of the former has been estimated as 6 EJ (144 Mtoe) and listed under "Renewables" in Table 1.1, and the latter as 39 EJ (936 Mtoe). This gives a total of 45 EJ (1,080 Mtoe) as indicated in Table 1.1, although some estimates make it slightly greater. Since the net global production of biomass is estimated as 2,280 EJ/year, so the percentage of the biomass used for fuel is 2 %. Food production on the other hand is equivalent to about 273 EJ/annum, that is approximately 12 %.

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